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(54) Title: NAPTHOQUINONE DERIVATIVES AS INHIBITORS OF TAU AGGREGATION FOR THE TREATMENT OF ALZHEIMER'S AND RELATED NEURODEGENERATIVE DISORDERS

(57) Abstract: Provided are napthoquinone-type compounds which can be used to modulate the aggregation of protein (e.g. tau) associated with neurodegenerative disease (e.g. Alzheimer's disease). Structure-function characteristics for oxidised and reduced napthoquinone-type compounds, such as menadione-related compounds, are disclosed. The invention further provides methods of treatment or prophylaxis of neurodegenerative diseases and/or clinical dementias based on the compounds.

WO 03/007933 A1

61

NAPTHOQUINONE DERIVATIVES AS INHIBITORS OF TAU AGGREGATION FOR THE TREATMENT OF ALZHEIMER'S AND RELATED NEURODEGENERATIVE DISORDERS

TECHNICAL FIELD

The present invention generally concerns the aggregation of proteins associated with neurodegenerative disease such as Alzheimer's disease (AD) and compounds capable of modulating such aggregation.

BACKGROUND TO INVENTION

Conditions of dementia such as AD are frequently characterised by a progressive accumulation of intracellular and/or extracellular deposits of proteinaceous structures such as β-amyloid plaques and neurofibrillary tangles (NFTs) in the brains of affected patients. The appearance of these lesions largely correlates with pathological neurofibrillary degeneration and brain atrophy, as well as with cognitive impairment (Mukaetova-Ladinska, E.B. *et al.* (2000) Am. J. Pathol. Vol. 157, No. 2, 623-636).

In AD, both neuritic plaques and NFTs contain paired helical filaments (PHFs), of which a major constituent is the microtubule-associated protein tau (Wischik *et al.* (1988a) PNAS USA 85, 4506-4510). Plaques also contain extracellular β-amyloid fibrils derived from the abnormal processing of amyloid precursor protein (APP; Kang *et al.* (1987) Nature 325, 733). An article by Wischik *et al.* (in 'Neurobiology of Alzheimer's Disease', 2nd Edition (2000) Eds. Dawbarn, D. and Allen, S.J., The Molecular and Cellular Neurobiology Series, Bios Scientific Publishers, Oxford) discusses in detail the putative role of tau protein in the pathogenesis of neurodegenerative dementias. Loss of the normal form of tau, accumulation of pathological PHFs and loss of synapses in the mid-frontal cortex all correlate with associated cognitive impairment. Furthermore, loss of synapses and loss of pyramidal cells both correlate with morphometric measures of tau-reactive neurofibrillary pathology, which parallels, at a molecular level, an almost total redistribution of the tau protein pool from a soluble to a polymerised form (i.e. PHFs) in Alzheimer's disease.

Tau exists in alternatively-spliced isoforms, which contain three or four copies of a repeat sequence corresponding to the microtubule-binding domain (Goedert, M., *et al.* (1989) *EMBO J.* 8, 393-399; Goedert, M., *et al.* (1989) *Neuron* 3, 519-526). Tau in PHFs is proteolytically processed to a core domain (Wischik, C.M., *et al.* (1988b) *PNAS. USA* 85, 4884-4888; Wischik *et al.* (1988a) *Loc cit.*); Novak, M., *et al.* (1993) *EMBO J.* 12, 365-370) which is composed of a phase-shifted version of the repeat domain; only three repeats are involved in the stable tau-tau interaction (Jakes, R., *et al.* (1991) *EMBO J.* 10, 2725-2729). Once formed, PHF-like tau aggregates act as seeds for the further capture and provide a template for proteolytic processing of full-length tau protein (Wischik *et al.* 1996 Proc Natl Acad Sci USA 93, 11213-11218).

The phase shift which is observed in the repeat domain of tau incorporated into PHFs suggests that the repeat domain undergoes an induced conformational change during incorporation into the filament. During the onset of AD, it is envisaged that this conformational change could be initiated by the binding of tau to a pathological substrate, such as damaged or mutated membrane proteins (see Wischik, C.M., *et al.* (1997) in "*Microtubule-associated proteins: modifications in disease*", eds. Avila, J., Brandt, R. and Kosik, K. S. (Harwood Academic Publishers, Amsterdam) pp.185-241).

In the course of their formation and accumulation, PHFs first assemble to form amorphous aggregates within the cytoplasm, probably from early tau oligomers which become truncated prior to, or in the course of, PHF assembly (Mena, R., *et al.* (1995) *Acta Neuropathol.* 89, 50-56; Mena, R., *et al.* (1996) *Acta Neuropathol.* 91, 633-641). These filaments then go on to form classical intracellular NFTs. In this state, the PHFs consist of a core of truncated tau and a fuzzy outer coat containing full-length tau (Wischik., C. M., *et al*, (1996) loc. cit.). The assembly process is exponential, consuming the cellular pool of normal functional tau and inducing new tau synthesis to make up the deficit (Lai, R. Y. K., et al., (1995), *Neurobiology of Ageing*, Vol. 16, No. 3, 433-

445). Eventually, functional impairment of the neurone progresses to the point of cell death, leaving behind an extracellular NFT. Cell death is highly correlated with the number of extracellular NFTs (Wischik *et al.* 2000, loc.cit). As tangles are extruded into the extracellular space, there is progressive loss of the fuzzy outer coat of the neurone with corresponding loss of N-terminal tau immunoreactivity, but preservation of tau immunoreactivity associated with the PHF core (Bondareff, W. *et al.*, (1994) *J. Neuropath. Exper. Neurol.*, Vol. 53, No. 2, 158-164).

Clearly the identification of compounds that could modulate the aggregation of disease-associated proteins such as tau is of great interest.

WO 96/30766 (F Hoffman-La Roche) discloses assays for the inhibition of tau-tau association, and certain inhibitors identified using the assays. Figures 23 and 24 therein rank certain compounds according to their inhibitory properties. Vitamin K (=K2) has a value of 0.674 and menadione (also known as Vitamin K3) is denoted as having a value of 1.042. In the ranking a value of 1 represents binding equivalent to that observed in the absence of compound.

Of course, vitamin K is well known, *per* se, as a therapeutic. A brief overview of Vitamin K is given in "Goodman and Gilman's The Pharmacological Basis of Therapeutics", 9th edition, pp 1582-1585, 1998. More comprehensive reviews are provided in William Friedrich, "Vitamins", pp 285-338, 1988; Thorp et al (1995), Drugs 49, 376-387; Vermeer and Schurgers (2000), Blood Stasis and Thrombosis, 14, 339-353. The reduced form of vitamin K acts as a cofactor for the enzyme gamma-glutamyl carboxylase. This enzyme is responsible for the conversion of glutamic acid residues to gamma-carboxyglutamate on the vitamin K - dependent clotting factors (factors II, VII, IX, X and the anticoagulation proteins, protein C and protein S). Other gamma-carboxyglutamic acid containing proteins (so called Gla-proteins) have been found in plasma (protein Z), bone (osteocalcin), kidney, lung and testicular tissue. The functions of non-haematological Gla-proteins are outlined in Vermeer and Schurgers (2000, *loc cit.*). However such proteins are not found in

the brain (Vermeer (1990), Biochem J, 266, 625-636).

Traditional therapeutic uses of Vitamin K analogues include hypoprothrominaemia in adults and the newborn, inadequate absorption of lipid-soluble substances, and intestinal malabsorbtion syndromes such as cystic fibrosis, sprue, Crohn's disease and enterocolitis.

In addition to the therapeutic uses described above, vitamin K3 is also known to have anti-tumour activity in vitro against a broad range of rodent and human tumour cell lines (Hu et al., 1996). The mechanism of this activity is not known. It has been shown that vitamin K3 has complex effects on several second messenger kinase cascades (Markovits et al., 1998; Wu and Sun 1999), and it has been proposed specifically that vitamin K3 forms a covalent bond with kinases/phsophatases containing the peptide sequence (I/V)HCXXXXXR(S/T)G inducing cell-cycle arrest and cell death by inhibitng Cdc25 phosphatase. However the consensus sequence [HCXXXXXR(S/T)G] is not found in the repeat domain of tau.

One study (Nakajima et al., 1993) examined the effects of vitamin K derivatives on cultured CNS neurones and found that vitamins K1 and K2 had prominent survival promoting effects in the range 10 nM - 1μM. By contrast, vitamin K3 (menadione) had only ~10% of this survival promoting activity, and this only at 1 μM. Whatever the mechanism of this effect, it was not dependent on the vitamin K cycle, since coumarin anticoagulant which interferes with epoxide reductase step had no effect on the survival promotion assay. Using cultured human neuroblastoma cells, Ko et al. (1997) showed that menadione at high doses (200 μM) caused both prominent dephosphorylation of tau protein, and oxidation of a broad range of proteins. Interestingly, for the reasons discussed in detail in Wischik et al. (2000), tau protein dephosphorylation might be expected to enhance tau protein aggregation.

More recently, Ko et al. (2000) discusses the role of pathogenic mutations in alpha-synuclein in sensitising neuronal cells to oxidative stress induced by high dose menadione. In this paper, the authors argue that thiol-depletion induced by compounds which

generate oxidative-stress is a general mechanism responsible for toxicity of mutant alpha-synuclein in hereditary Parkinson's disease, with the implication that rational approaches to therapy would be based on *counteracting* the oxidant damage produced by substances such as menadione.

However, apart from the isolated data given in WO 96/30766 (F Hoffman-La Roche), no investigation has been carried out to demonstrate and optimise a role for napthoquinone-type compounds in the inhibition of aggregation of protein associated with neurodegenerative disease.

DISCLOSURE OF THE INVENTION

The present inventors have investigated the structures of napthoquinone-type compounds which can be used to inhibit the aggregation of protein associated with neurodegenerative disease. Using novel assay technology they have demonstrated that, contrary to the data given in WO 96/30766, menadione and related compounds may be highly effective inhibitors. Detailed structure-function characteristics for napthoquinone-type compounds, such as Vitamin K-derived compounds, have been determined in respect of their use as protein (e.g. tau protein) aggregation inhibitors. As will be appreciated by those skilled in the art, in the light of the present disclosure, these results demonstrate utility for such compounds *inter alia* in the treatment of diseases (such as AD) associated with such protein aggregation.

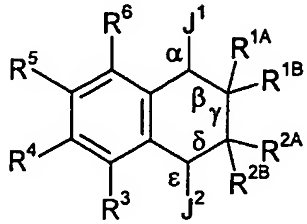
More specifically, the inventors have determined that it may be advantageous for potency that the '3' position group, generally substituent R^{2A} in the structural formulae below, be absent or relatively short (e.g. as in menadione) rather than an extended group (e.g. as in Vitamin K2 or K3). This is not only unexpected in the light of WO 96/30766, but also in the light of earlier more general structure function relationships for these compounds. For example in: Isler and Wiss (1959), Vitamins and Hormones, 17, 53-90, at page 77, the "biological activity" of Vitamin K1 and K2, and their analogs, is shown to decrease as the '3' position side chain is shortened.

Compounds of the invention

Aspects of the present invention are based on uses of Vitamin K-type compounds having relatively short groups, or no group, at the 3' position (as defined in more detail below) in relation to neurodegenerative diseases of protein aggregation.

As described above, the class of compounds known as "Vitamin K" correspond in their naturally occurring forms to a dietary principle essential for the normal biosynthesis of several factors required for the clotting of blood. This activity is associated with at least two distinct naturally occurring substances, designated vitamin K1 (phytonadione, or 2-methyl-3-phytyl-1,4-naphthoquinone, the form occurring in leafy vegetables) and vitamin K2 (menaquinone). The latter represent a series of compounds (the menaquinones) in which the phytyl side chain of phytonadione is replaced by a side chain built of 2 to 13 prenyl units, and numbered accordingly. Intestinal bacteria and liver are able synthesise menaquinones (predominantly manaquinone-4) from the synthetic lipid-soluble analogue menadione. Menadione has 2 common water-soluble derivatives, menadiol sodium phosphate and menadione sodium bisulphate which are converted to menadione after administration. Other compounds related to menadione have been investigated for anti-tumour activity, in particular compounds related to lapachol (2 hydroxy-3-(3-methyl-2-butenyl)-1,4-naphthoquinone). Structural variants in the side-chain at position 3 are reviewed by Rao (1974). Some typical toxicological and clinical data for lapachol are provided by Seiber et al. (1976) and Morrison et al. (1970).

The invention particularly pertains to compounds of the following formula:



I

wherein:

J^1 and J^2 are both =O; i.e. the covalent bonds marked α and ε are double bonds; β and δ are single bonds,

and the covalent bond marked γ is a double bond with R^{1B} and R^{2B} both absent;

or

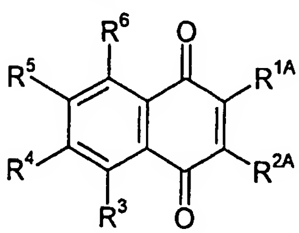
the covalent bond marked γ is a single bond.

In another embodiment:

J^1 is $-OR^7$ and J^2 is $-OR^8$; i.e. the covalent bonds marked α and ε are single bonds; β and δ are double bonds, and the covalent bond marked γ is a single bond with R^{1B} and R^{2B} both absent.

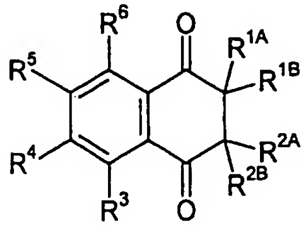
Both oxidised and reduced forms of the compounds described herein may be used in the present invention.

Thus in particular embodiments, the compounds have the following formula:



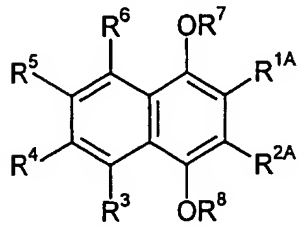
II

In one embodiment, the compounds have the following formula:



III

In one embodiment, the compounds have the following formula:



IV

Various preferred, specific, embodiments are shown in Figure 2 with Vitamin K1 and K2, and certain other inactive compounds not forming part of the present invention, being included for comparison.

R^{2A} and *R^{2B}* if present

Compounds of the invention are those in which R^{2A} is a relatively short group (compare K1 and K2 with DH10 and K3 for example).

Thus R^{2A} may be independently selected from -H, C_{1-7}alkyl (including, e.g. unsubstituted C_{1-7}alkyl, substituted C_{1-7}alkyl such as C_{1-7}haloalkyl, C_{1-7}hydroxyalkyl, C_{1-7}aminoalkyl, C_{1-7}carboxyalkyl etc.), -OH, C_{1-7}alkoxy, acyloxy, -COOH, ester, $-SO_3H$, $-SO_3M$, sulfonate, C_{1-7}alkylsulfonate, or a "short chain alkyl group" by which is meant linear or branched alkyl group having from 1-15 carbon atoms, most preferably 1-12, more preferably 1-10, e.g. 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10 carbon atoms, which may be saturated or partially unsaturated.

The term "C_{1-7}haloalkyl group," as used herein, pertains to a C_{1-7}alkyl group in which at least one hydrogen atom (e.g., 1, 2, 3) has been replaced with a halogen atom (e.g., F, Cl, Br, I). If more than one hydrogen atom has been replaced with a halogen atom,

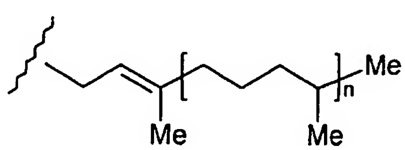
the halogen atoms may independently be the same or different. Every hydrogen atom may be replaced with a halogen atom, in which case the group may conveniently be referred to as a C_{1-7}perhaloalkyl group." Examples of C_{1-7}haloalkyl groups include, but are not limited to, $-CF_3$, $-CHF_2$, $-CH_2F$, $-CCl_3$, $-CBr_3$, $-CH_2CH_2F$, $-CH_2CHF_2$, and $-CH_2CF_3$.

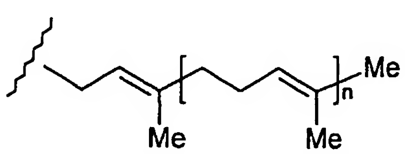
The term "C_{1-7}hydroxyalkyl group," as used herein, pertains to a C_{1-7}alkyl group in which at least one hydrogen atom has been replaced with a hydroxy group. Examples of C_{1-7}hydroxyalkyl groups include, but are not limited to, $-CH_2OH$, $-CH_2CH_2OH$, and $-CH(OH)CH_2OH$.

The term "C_{1-7}aminoalkyl group," as used herein, pertains to a C_{1-7}alkyl group in which at least one hydrogen atom has been replaced with an amino group. Examples of C_{1-7}aminoalkyl groups include, but are not limited to, $-CH_2NH_2$, $-CH_2CH_2NH_2$, and $-CH_2CH_2N(CH_3)_2$.

The term "C_{1-7}carboxyalkyl group," as used herein, pertains to a C_{1-7}alkyl group in which at least one hydrogen atom has been replaced with a carboxy group. Examples of C_{1-7}carboxyalkyl groups include, but are not limited to, $-CH_2COOH$ and $-CH_2CH_2COOH$.

In one embodiment, the short chain alkyl group is one of the following groups, wherein n is 0, 1, or 2:





R^{2B} if present will be selected from the same groups as R^{2A}, and may be the same or different to R^{2A}. However preferred compounds are those in which R^{2B} is absent.

R^{1A}, R^{1B}

Each of R^{1A}, R^{1B} is independently -H, C_{1-7}alkyl (including, e.g. unsubstituted C_{1-7}alkyl, substituted C_{1-7}alkyl such as C_{1-7}haloalkyl, C_{1-7}hydroxyalkyl, C_{1-7}aminoalkyl, C_{1-7}carboxyalkyl etc.), -OH, C_{1-7}alkoxy, acyloxy, -COOH, ester, $-SO_3H$, $-SO_3M$, sulfonate, C_{1-7}alkylsulfonate, or a short chain alkyl group.

M denotes a cation or cations of charge or cumulative charge to counter the charge on the $-SO_3^-$ group. In one embodiment, M denotes an alkali ion, such as Li^+, Na^+, K^+, or Cs^+, more preferably Na^+ or K^+.

Preferred compounds are those in which R^{1B} is absent, although compounds in which it is not absent (such as DH3 for example) do show activity.

Preferred compounds are those in which R^{1A} is alkyl, such as methyl (compare DH2 and DH14 for example, also DH1, DH7 and DH15). However other small groups in place of methyl, such as a sulphate group, may also be preferred (compare K3 and DH8). Preferably the R^{1A} group is an electron donating group.

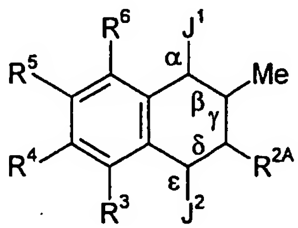
R^{1A}, R^{1B}, R^{2A}, R^{2B}

In one embodiment, each of R^{1A}, R^{1B}, R^{2A}, R^{2B} is independently -H; -Me, -Et, -nPr, -iPr, -nBu, -sBu, -iBu, -tBu; -OH; -OMe, -OEt, -O(nPr), -O(iPr), -O(nBu), -O(sBu), -O(iBu), -O(tBu); -OC(=O)Me, -OC(=O)Et, -OC(=O)(nPr), -OC(=O)(iPr), -OC(=O)(nBu), -OC(=O)(sBu), -OC(=O)(iBu), or -O(C=O)(tBu); -C(=O)OMe, -C(=O)OEt, -C(=O)O(nPr), -C(=O)O(iPr), -C(=O)O(nBu), -C(=O)O(sBu), -C(=O)O(iBu), -C(=O)O(tBu); $-SO_3H$, $-SO_3M$, $-SO_3Me$, $-SO_3Et$, $-SO_3(nPr)$, $-SO_3(iPr)$, $-SO_3(nBu)$, $-SO_3(sBu)$, $-SO_3(iBu)$, $-SO_3(tBu)$.

In one embodiment, each of R^{1A}, R^{1B}, R^{2A}, R^{2B} is independently -H, -Me, -Et, -OMe, -OEt, -OH, -OMe, -OEt, -OC(=O)Me, -OC(=O)Et, -COOH, -COOMe, -COOEt, $-SO_3H$, $-SO_3M$, $-SO_3Me$, $-SO_3Et$, or $-CH_2CH=C(CH_3)_2$.

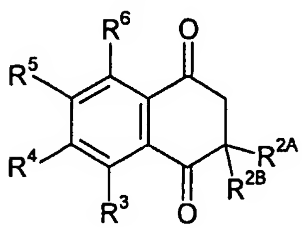
In one embodiment, each of R^{1A}, R^{1B}, R^{2A}, R^{2B} is independently -H, -Me, -OMe, -OH, -OMe, -OC(=O)Me, -COOH, -COOMe, $-SO_3H$, $-SO_3M$, $-SO_3Me$, or $-CH_2CH{=}C(CH_3)_2$.

In one embodiment, R^{1A} is -Me, and R^{1B} and R^{2B} are absent:



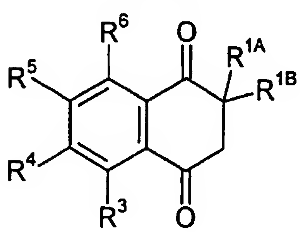
V

In one embodiment, R^{1A} and R^{1B} are both -H, and R^{2A} and R^{2B} are as defined above:



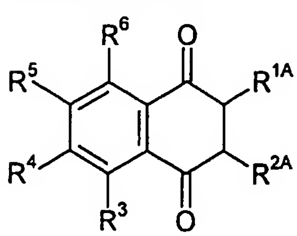
VI

In one embodiment, R^{2A} and R^{2B} are both -H, and R^{1A} and R^{1B} are as defined above:



VII

In one embodiment, R^{1B} and R^{2B} are both -H, and R^{1B} and R^{2B} are as defined above:



VIII

R^3, R^4, R^5, and R^6

Each of R^3, R^4, R^5, and R^6 is independently -H, -OH, C_{1-7}alkyl (including, e.g. unsubstituted C_{1-7}alkyl, substituted C_{1-7}alkyl such as C_{1-7}haloalkyl, C_{1-7}hydroxyalkyl, C_{1-7}aminoalkyl, C_{1-7}carboxyalkyl etc.), C_{1-7}alkoxy, or acyloxy.

The presence or absence of substituents at R^3, R^4, R^5, or R^6 does not appear to greatly affect activity(compare K3 and DH2 for example).

In one embodiment, each of R^3, R^4, R^5, and R^6 is independently -H, -OH, C_{1-7}alkyl, C_{1-7}alkoxy, or C_{1-7}alkylacyloxy.

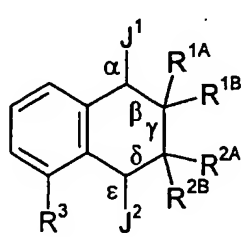
In one embodiment, each of R^3, R^4, R^5, and R^6 is independently: -H; -OH; -Me, -Et, -nPr, -iPr, -nBu, -sBu, -iBu, -tBu; -OMe, -OEt, -O(nPr), -O(iPr), -O(nBu), -O(sBu), -O(iBu), -O(tBu); -OC(=O)Me, -OC(=O)Et, -OC(=O)(nPr), -OC(=O)(iPr), -OC(=O)(nBu), -OC(=O)(sBu), -OC(=O)(iBu), or -O(C=O)(tBu).

In one embodiment, each of R^3, R^4, R^5, and R^6 is independently: -H; -OH; -Me, -Et; -OMe, -OEt; -OC(=O)Me, or -OC(=O)Et.

In one embodiment, each of R^3, R^4, R^5, and R^6 is independently: -H; -OH; -Me; -OMe; or -OC(=O)Me.

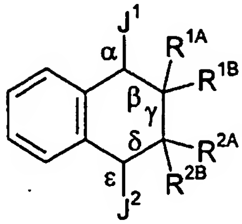
In one embodiment, each of R^3, R^4, R^5, and R^6 is independently: -H or -OH.

In one embodiment, each of R^4, R^5, and R^6 is -H, and R^3 is as defined above:



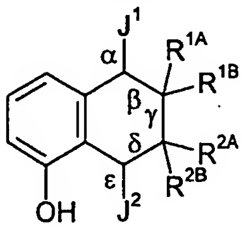
IX

In one embodiment, each of R^4, R^5, and R^6 is -H, and R^3 is -H:



X

In one embodiment, each of R^4, R^5, and R^6 is -H, and R^3 is -OH:



XI

J^1 and J^2

As demonstrated in the examples, compounds in which J^1 and J^2 are both =O, or in which they are $-OR^7$ and $-OR^8$ respectively, may both have high activities (compare K3 and DH9 for example; also DH5).

Thus, referring to formula IV above, each of R^7 and R^8 is independently -H, C_{1-7}alkyl (including, e.g. unsubstituted C_{1-7}alkyl, substituted C_{1-7}alkyl such as C_{1-7}haloalkyl, C_{1-7}hydroxyalkyl, C_{1-7}aminoalkyl, C_{1-7}carboxyalkyl etc.), acyl (including, e.g., C_{1-7}alkylacyl, e.g., acetyl), $-SO_3H$, $-SO_3M$, or sulfonate.

The term "acyl," as used herein, pertains to a group -C(=O)R, wherein R is an acyl substituent, for example, a C_{1-7}alkyl group (also referred to as C_{1-7}alkylacyl or C_{1-7}alkanoyl), a C_{3-20}heterocyclyl group (also referred to as C_{3-20}heterocyclylacyl), or a C_{5-20}aryl group (also referred to as C_{5-20}arylacyl), preferably a C_{1-7}alkyl group. Examples of acyl groups include, but are not limited to, $-C(=O)CH_3$ (acetyl), $-C(=O)CH_2CH_3$ (propionyl), $-C(=O)C(CH_3)_3$ (t-butyryl), and -C(=O)Ph (benzoyl, phenone).

In one embodiment, R^7 and R^8 are the same.
In one embodiment, R^7 and R^8 are different.

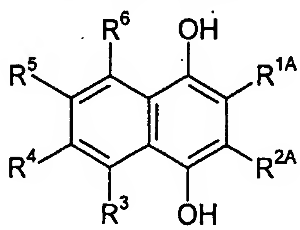
In one embodiment, each of R^7 and R^8 is independently -H, C_{1-7}alkyl, C_{1-7}alkylacyl, $-SO_3H$, $-SO_3M$, or C_{1-7}alkylsulfonate.

In one embodiment, each of R^7 and R^8 is independently -H; -Me, -Et, -nPr, -iPr, -nBu, -sBu, -iBu, -tBu; -C(=O)Me, -C(=O)Et, -C(=O)(nPr), -C(=O)(iPr), -C(=O)(nBu), -C(=O)(sBu), -C(=O)(iBu), or -(C=O)(tBu); $-SO_3H$, $-SO_3M$, $-SO_3Me$, $-SO_3Et$, $-SO_3(nPr)$, $-SO_3(iPr)$, $-SO_3(nBu)$, $-SO_3(sBu)$, $-SO_3(iBu)$, or $-SO_3(tBu)$.

In one embodiment, each of R^7 and R^8 is independently -H; -Me, -Et, -C(=O)Me, -C(=O)Et, $-SO_3H$, $-SO_3M$, $-SO_3Me$, or $-SO_3Et$.

In one embodiment, each of R^7 and R^8 is independently -H; -Me, -C(=O)Me, $-SO_3H$, $-SO_3M$, or $-SO_3Me$.

In one embodiment, each of R^7 and R^8 is -H:



XII

Preferred compounds of the present invention are those which show high activity in the assays described herein, particularly 'cell based assay I' described below. Preferred compounds have a B50 of less than 10, more preferably less than 5. Likewise they will have a low toxicity, with an Rxindx of greater than 4, more preferably greater than 10.

As used hereinafter, unless context demands otherwise, the term "vitamin K compound" is intended to encompass any of these compounds such as (for example only) menadione, menadiol and diesters thereof, and analogs of any of these in accordance with the formulae given herein.

Uses of the present invention

In one aspect there is disclosed use of a vitamin K compound to inhibit the aggregation of a protein, which aggregation is associated with a disease state.

In general, the protein aggregation to which the present invention may be applied is that which arises from an induced conformational polymerisation interaction i.e. one in which a conformational change of the protein, or in a fragment thereof, gives rise to templated binding and aggregation of further (precursor) protein molecules in a self-propagating manner. Once nucleation is initiated, an aggregation cascade may ensue which involves the induced conformational polymerisation of further protein molecules, leading to the formation of toxic product fragments in aggregates which are substantially resistant to further proteolysis. The protein aggregates thus formed are thought to be a proximal cause of disease states manifested as neurodegeneration, clinical dementia, and other pathological symptoms.

Uses in relation to Tau protein

Preferred embodiments of the invention are based on inhibition of tau protein aggregation. Where used herein, the term "tau protein" refers generally to any protein of the tau protein family. Tau proteins are characterised as being one among a larger number of protein families which co-purify with microtubules during repeated cycles of assembly and disassembly (Shelanski *et al.* (1973) Proc. Natl. Acad. Sci. USA, 70., 765-768), and are known as microtubule-associated-proteins (MAPs). Members of the tau family share the common features of having a characteristic N-terminal segment, sequences of approximately 50 amino acids inserted in the N-terminal segment, which are developmentally regulated in the brain, a characteristic tandem repeat region consisting of 3 or 4 tandem repeats of 31-32 amino acids, and a C-terminal tail.

MAP2 is the predominant microtubule-associated protein in the somatodendritic compartment (Matus, A., in "*Microtubules*" [Hyams and Lloyd, eds.] pp 155-166, John Wiley and Sons, NY). MAP2 isoforms are almost identical to tau protein in the tandem repeat region, but differ substantially both in the sequence and extent of

the N-terminal domain (Kindler and Garner (1994) Mol. Brain Res. 26, 218-224). Nevertheless, aggregation in the tandem-repeat region is not selective for the tau repeat domain. Thus it will be appreciated that any discussion herein in relation to tau protein or tau-tau aggregation should be taken as relating also to tau-MAP2 aggregation, MAP2-MAP2 aggregation and so on.

Other proteins

Figure 4 shows a Table listing various other disease-associated aggregating proteins, the inhibition of which forms part of the present invention. In each case the disease or diseases in which the initiation of aggregation and\or mutation of the protein(s) may play a role is also listed.

As can be seen from the table, example diseases which are characterised by pathological protein aggregation include motor neurone disease and Lewy body disease. Furthermore, the pathogenesis of neurodegenerative disorders such as Pick's disease and Progressive Supranuclear Palsy appears to correlate with an accumulation of pathological tau aggregates in the dentate gyrus and stellate pyramidal cells of the neocortex, respectively (Wischik *et al.* 2000, loc. cit). Other 'tauopathies' to which the present invention may be applied include Familial Multiple System Tauopathy, Corticobasal Degeneration, and Familial Gerstmann-Straussler-Scheinker Disease.

Thus it will be appreciated, in the light of the above discussion, (and except where context requires otherwise) where the embodiments of the invention are described with respect to tau protein or tau-like proteins (e.g. MAP2) the description should be taken as applying equally to the other proteins discussed above (e.g. β-amyloid, synuclein, prion etc.) or other proteins which may initiate or undergo a similar pathological aggregation by virtue of conformational change in a domain critical for propagation of the aggregation, or which imparts proteolytic stability to the aggregate thus formed (article by Wischik *et al.* (in "Neurobiology of Alzheimer's Disease", 2nd Edition (2000) Eds. Dawbarn, D. and Allen, S.J., The Molecular and Cellular Neurobiology Series, Bios

Scientific Publishers, Oxford). All such proteins may be referred to herein as "aggregating disease proteins." The diseases may be referred to herein as "diseases of protein aggregation".

Likewise, where mention is made herein of "tau-tau aggregation", or the like, this may also be taken to be applicable to other aggregation of other proteins which have similar properties in this respect, such as β-amyloid aggregation, prion aggregation and synuclein aggregation etc. Likewise "tau proteolytic degradation" and so on.

Other uses and methods

As described above, in one aspect there is disclosed use of a vitamin K compound to inhibit the aggregation of a protein, which aggregation is associated with a disease state as described above.

A further embodiment is a method of treatment or prophylaxis of a disease of protein aggregation as described above, which method comprises administering to a subject a vitamin K compound, or therapeutic composition comprising the same, such as to inhibit the aggregation of the protein associated with said disease state.

In a further embodiment there is disclosed a Vitamin K compound, or therapeutic composition comprising the same, for use in a method of treatment or prophylaxis of a disease of protein aggregation as described above, which method comprises administering to a subject the vitamin K compound or composition such as to inhibit the aggregation of the protein associated with said disease state.

In a further embodiment there is disclosed use of a Vitamin K compound in the preparation of a medicament for use in a method of treatment or prophylaxis of a disease of protein aggregation as described above, which method comprises administering to a subject the medicament such as to inhibit the aggregation of the protein associated with said disease state.

In one embodiment there is disclosed a method of regulating the aggregation of a protein in the brain of a mammal, which

aggregation is associated with a disease state as described above, the treatment comprising the step of administering to said mammal in need of said treament, a prophylactically or therapeutically effective amount of an inhibitor of said aggregation, wherein the inhibitor is a Vitamin K compound.

In another embodiment of the present invention, there is provided a method of inhibiting production of protein aggregates (e.g. in the form of PHFs, optionally in NFTs) in the brain of a mammal, the treatment being as described above.

Vitamin K compounds may be administered alone, or in combination with other treatments, either simultaneously or sequentially, dependent upon the condition or disease to be treated. In particular it may be desired to use or formulate Vitamin K compounds with other inhibitors of the relevant protein aggregation reaction e.g. in the case of Tau this may be compounds as described in WO 96/30766 or prior filed, unpublished application GB 0101049.5, the contents of which are incorporated herein by reference.

Other therapeutic agents for treating e.g. AD with which the present invention may be combined include cholinesterase inhibitors such as donepezil, muscarinic receptor agonists, and inhibitors of beta-amyloid.

A further aspect of the present provides a therapeutic combination composition comprising a vitamin K compound plus one further compound.

Dosage of therapeutics

Administration of compounds, compositions or medicaments as described herein is preferably in a "prophylactically effective amount" or a "therapeutically effective amount" (as the case may be, although prophylaxis may be considered therapy), this being sufficient to show benefit to the individual. The actual amount administered, and rate and time-course of administration, will depend on the nature and severity of the disease being treated.

Prescription of treatment, e.g. decisions on dosage etc., is within the responsibility of general practitioners and other medical doctors, and typically takes account of the disorder to be treated, the condition of the individual patient, the site of delivery, the method of administration and other factors known to practitioners.

Typically the mammal will be human, although use in animals (e.g. for test purposes, or veterinary therapeutic purposes) is also embraced by the invention.

The recommended daily allowances for Vitamin K vary between about 10-20 µg/day (infant); 15-60 µg/day (children and youths up to 11 years), and 50-140 µg/day (children over 11 years and adult) (RDAs for US, 1980). Other reports recommend 0.01-0.03 mg/kg body weight (see Friedrich, 1988, *loc cit*, discussion page 319-320). Vitamin K-type compounds, such as those used in the present invention, may be administered in an amount greater than or equal to about 10 mg/per day or more for a 70 kg adult (according to British National Formulary data released by the BMA and Royal Pharmaceutical Society of Great Britain).

Formulation and administration of therapeutics

Suitable compounds, such as those with a formula as shown above or their pharmaceutically-acceptable salts, may be incorporated into compositions of this aspect of the present invention after further testing for toxicity.

The compositions may include, in addition to the above constituents, pharmaceutically-acceptable excipients, preserving agents, solubilizers, viscosity-increasing substances, stabilising agents, wetting agents, emulsifying agents, sweetening agents, colouring agents, flavouring agents, salts for varying the osmotic pressure, buffers, or coating agents. Such materials should be non-toxic and should not interfere with the efficacy of the active ingredient. The precise nature of the carrier or other material may depend on the route of administration. Examples of techniques and protocols can be found in "*Remington's Pharmaceutical Sciences*", 16th edition, Osol, A. (ed.), 1980. Compounds affecting

the stability of menadione (vitamin k3) are discussed by Daabis & Khawas (1969 Pharmazie 24, 750) and Fattah and Daabis (1977 Pharmazie 32 H.4, 232).

Where the composition is formulated into a pharmaceutical composition, the administration thereof can be effected parentally such as orally, in the form of powders, tablets, coated tablets, dragees, hard and soft gelatine capsules, solutions, emulsions or suspensions, nasally (e.g. in the form of nasal sprays) or rectally (e.g. in the form of suppositories). However, the administration can also be effected parentally such as intramuscularly, intravenously, cutaneously, subcutaneously, or intraperitoneally (e.g. in the form of injection solutions).

Thus, for example, where the pharmaceutical composition is in the form of a tablet, it may include a solid carrier such as gelatine or an adjuvant. For the manufacture of tablets, coated tablets, dragees and hard gelatine capsules, the active compounds and their pharmaceutically-acceptable acid addition salts can be processed with pharmaceutically inert, inorganic or organic excipients. Lactose, maize, starch or derivatives thereof, talc, stearic acid or its salts etc. can be used, for example, as such excipients for tablets, dragees and hard gelatine capsules. Suitable excipients for soft gelatine capsules are, for example, vegetable oils, waxes, fats, semi-solid and liquid polyols etc. Where the composition is in the form of a liquid pharmaceutical formulation, it will generally include a liquid carrier such as water, petroleum, animal or vegetable oils, mineral oil or synthetic oil. Physiological saline solution, dextrose or other saccharide solution or glycols such as ethylene glycol, propylene glycol or polyethylene glycol may also be included. Other suitable excipients for the manufacture of solutions and syrups are, for example, water, polyols, saccharose, invert sugar, glucose, trihalose, etc. Suitable excipients for injection solutions are, for example, water, alcohols, polyols, glycerol, vegetable oils, etc. For intravenous, cutaneous or subcutaneous injection, or intracatheter infusion into the brain, the active ingredient will be in the form of a parenterally-acceptable aqueous solution which is pyrogen-free and has suitable pH, isotonicity and stability. Those of relevant

skill in the art are well able to prepare suitable solutions using, for example, isotonic vehicles such as Sodium Chloride Injection, Ringer's Injection, Lactated Ringer's Injection. Preservatives, stabilisers, buffers and/or other additives may be included, as required.

Oral and parental preparations of vitamin K1 and of vitamin K3 are available commercially (albeit not for the uses disclosed herein).

The disclosure of any cross-reference made herein, inasmuch as it may be required by one skilled in the art to supplement the present disclosure, is hereby specifically incorporated herein.

The invention will now be further described with reference to the following non-limiting Figures and Examples. Other embodiments of the invention will occur to those skilled in the art in the light of these.

FIGURES

Figure 1 - shows *in vitro* tau-tubulin binding in the presence of Vitamin K2.

Figure 2a shows the structures of vitamins K1 - K3 and 2,3-dimethyl-1,4-naphthoquinone (denoted DH10).

Figure 2b shows two 5-hydroxy 1,4-naphthoquinone derivatives (denoted DH14 and DH2). A further compound (denoted DH16) is included for comparison.

Figure 2c shows the effect of the presence of a hydroxy in the 2′ position in three compounds (denoted DH15, DH7, and DH1).

Figure 2d shows the effect of the presence of a sulphate and bisulphite group in the 2′ position (compounds denoted DH8, DH3). Also shown is an alkoxy derivative of the present invention (DH17), and a further compound (denoted DH19, which includes a halide) which is included for comparison.

Figure 2e shows two 1,4-naphthoquinols were examined (compounds denoted DH4, DH5).

Figure 2f shows the effect of acetate and sulphate substitutions (compounds denoted DH9, DH11, DH13).

Figure 2g shows the effect of alkoxy and methyl substitutions (compound denoted DH18) and a further compound (denoted DH20, which includes a halide) which is included for comparison.

Figure 3a and 3b show the tau-tau aggregation inhibition using cell based assay II.

Figure 4 shows a Table listing various other disease-associated aggregating proteins which may be used in the present invention.

Figure 5 is a schematic representation of the *in vitro* aggregation assay of WO 96/30766 in which binding of two truncated units is measured. The species terminating at Ala-390 ("a") is first coated on the ELISA plate (in sodium carbonate buffer: 50mM, pH 9.6). Next, a second truncated tau species terminating at Glu-391 ("e") is incubated in various buffer conditions. Only the species "e" is recognised by mAb 423, and hence mAb 423 immunoreactivity measures only that tau which is bound during the second incubation.

Figure 6a is a schematic representation of the process upon which cell-based assay I ('T40/12kD') is based. It shows how induction of full-length tau can lead to its conversion into the 12 kD fragment, provided there is some preexisting 12 kD tau in the cell. Figures 6b-e are examples results obtained from the assay using DH15 (negative result), vitamin K3, DH9 and DH17.

Figure 7 is a schematic representation of the cell-based assay II ('SSK40/25kD').

EXAMPLES

Methods

In vitro assay

This is described in detail in WO 96/30766. Briefly, a fragment of tau corresponding to the core repeat domain, which has been adsorbed to a solid phase substrate, is able to capture soluble full-length tau and bind tau with high affinity. This association confers stability against proteolytic digestion of the aggregated tau molecules. The process is self-propagating, and can be blocked selectively by prototype pharmaceutical agents (Wischik, C.M., *et al.* (1996), *loc. cit*).

The assay is shown schematically in Figure 5.

Cell-based assay I ('T40/12kD')

In essence, fibroblast cells (3T6) express full-length tau ("T40") under control of an inducible promotor, and low constitutive levels of the PHF-core tau fragment (12 kD fragment). When T40 expression is induced, it undergoes aggregation-dependent truncation within the cell, N-terminally at ~ αα 295 and C-terminally at ~ αα 390, thereby producing higher levels of the 12 kD PHF-core domain fragment. Production of the 12 kD fragment can be blocked in a dose-dependent manner by tau-aggregation inhibitors. Indeed the quantitation of inhibitory activity of compounds with respect to proteolytic generation of the 12 kD fragment within cells can be described entirely in terms of the same parameters which describe inhibition of tau-tau binding in vitro. That is, extent of proteolytic generation of the 12 kD fragment within cells is determined entirely by the extent to tau-tau binding through the repeat domain. The availability of the relevant proteases within the cell is non-limiting.

The process is shown schematically in Figure 6a, with example results being shown in Figures 6b-6d. The process is described in more detail in prior filed unpublished application GB 0101049.5.

Parameters used in cell-based assay I

The observed cell data for production of the 12 kD band can be

fitted closely (i.e. observed vs. predicted correlation coefficient > 0.9), to a standard function describing inhibition of tau-tau binding in vitro. To obtain this fit, two assumptions need to be made, which are consistent with results from other cell-based and in vitro studies:

1) the intracellular concentration of tau is approximately 500 nM;

2) the tau-tau binding affinity is 22 nM.

When these assumptions are made, the function:

Activity = [tau]([tau] + Kd * (1+ [inhibitor] / KI))

can be solved by standard numerical methods to derive a value for apparent KI. Comparison with values observed for tau-tau binding in vitro at a tau concentration of 500 nM, where the Kd value for tau-tau binding is known to be 22 nM confirm that the sole determinant of production of the proteolytically stable core tau unit of the PHF within the cell is simply the extent of tau-tau binding.

A further parameter, B50, has been established in respect of compounds exemplified herein. The B50 value is the determined concentration of test compound used in the cell assay at which relative production of the 12 kD band from full-length tau was reduced to 50% of that observed in the absence of the compound. This provides an indication of the tissue concentration which would be required to achieve the corresponding activity in vivo. In general there is an approximately linear relationship between apparent KI value and B50 value, which can be used to derive the KI value:

B50 (μM) = 0.0217 x KI (nM)

Cell-based assay II('ssK40/25kD')

The process is described in more detail in prior filed unpublished application GB 0100119.7. As demonstrated therein, the constitutive expression of membrane-targeted tau (sstau190-441, "ssK40") results in production of two specific cleavage products: a

minor 30 kD species ("K30") in which the fragment is C-terminally truncated at residue ~ 390, and a major 25 kD species ("K25") in which the fragment is N-terminally truncated at residue ~ 295. These cleavage sites correspond to the known boundaries of the PHF-core domain, indicate that their generation within the cell depends on PHF-like tau aggregation through an antiparallel phase-shifted alignment of the repeat domain.

This is shown schematically in Figure 7. When expression of full-length tau (T40) is activated under control of an inducible promoter in cells which constitutively express the membrane-targeted ssK40 fragment, T40 is processed proteolytically to give rise to a K40 fragment (N-terminal truncation at ~ αα 185), a K30 fragment (C-terminal truncation ~ αα 390) and a K25 fragment (N-terminal truncation at ~ αα 295).

Example 1 - *In vitro* tau-tau and tau-tubulin binding

Vitamin K2 was found to have some activity in the tau-tau binding assay in vitro. For values less than 100 μM, the apparent KI value in vitro is 942 nM. However, Vitamin K2 does not inhibit tau-tubulin binding in vitro at concentrations up to 500 μM (i.e. 2500:1 molar ratio with respect to tau in the conditions of the assay) - see Figure 1.

Further data (not shown) demonstrated that DH3 (Figure 2d) caused inhibition at concentrations greater than or equal to 50 μM (with tau concentration 100 nm). However menadione (Figure 2a) did not show activity in the *in vitro* assay, possibly due to its reduced solubility.

On this basis, further structure-activity characterisation was undertaken using the cell based assays which can be more readily used with compounds of different solubilities.

Example 2 - Tau-tau inhibition using cell based assay I

Figure 2a shows the structures of vitamins K1 - K3 and 2,3-

dimethyl-1,4-naphthoquinone (denoted DH10) which is closely related to K3 (2-methyl-1,4-naphthoquinone(menadiol)).

The corresponding values are listed for apparent KI and B50 calculated from the cell data using the T40/12kD cell assay to determine extent of inhibition of tau-tau binding as described above.

By comparing structures with inhibitory activity in cells, it is apparent that longer side-chains at the 3′ position are associated with reduced activity.

Figure 2b shows two 5-hydroxy 1,4-naphthoquinone derivatives. Comparison of DH14 and DH2 suggests that the methyl group in the 3′ position may be preferred to enhance activity, and that the hydroxy group in the 5′ position is not detrimental. DH2 proved to be the most highly toxic of all the compounds tested, with a cellular LD50 value of 2.1 µM. The DH16 compound did not show any activity.

Figure 2c shows the effect of the presence of a hydroxy in the 2′ position in three compounds. As can be seen from DH15 and DH17, a hydroxy in the 2′ position appears to be detrimental to activity. However, weak activity can be observed with the 3-prenyl derivative (DH1).

Figure 2d shows the effect of the presence of a sulphate group in the 2′ position. As can be seen, a sulphate group can be accommodated in this position without substantial loss of activity. However the bisuphite (a form of K3 widely used as an animal food supplement) has reduced activity. The methoxy derivative (DH17) showed good activity, as expected by comparison with vitamin K_3 in Figure 2a. The compound shown as DH19 showed no activity as an inhibitor of aggregation, and indeed it appeared that it may be a pro-aggregant (results not shown). This suggests that compounds having the enolisation properties of DH19 may be undesirable.

Figure 2e shows the results obtained when two 1,4-naphthoquinols were examined. The dicarbonitrile was entirely inactive, the

naphthoic acid form had activity in preliminary experiments. Naphthoic acid is generally present in vegetables, and is the natural precursor for synthesis of the higher naphthoquinones in leafy vegetables and bacteria.

Figure 2f shows the effect of acetate and sulphate substitutions in the 1 and 4 positions. As can be seen from this series, the 2-methyl diacetate (DH9) is highly active, whereas the 2,3-dimethyl diacetate (DH11) has reduced activity, as with the corresponding naphthoquinones. The 2-methyl disulphate is intermediate in activity.

Figure 2g shows a compound related to DH10 in Figure 2a, but wherein a methyl group has been replaced with a methoxy (DH18). Again this has activity (cf. DH17 and K3). The compound shown as DH20 showed no activity as an inhibitor of aggregation, and indeed it appeared that it may be a pro-aggregant (results not shown).

Example 3 - Tau-tau inhibition using cell based assay II

To confirm the results obtained using cell based assay I, further experiments were performed with cell based assay II.

Figures 3a and 3b show that this proteolytic processing can be blocked in this system using Vitamin K3 (menadione) at concentrations of 1 - 2 μM. Figure 3a shows that the conversion of T40 → K25 is reduced to about ¼ of that seen without K3, and Figure 3b shows that the conversion K40 → K25 is reduced to about ½ of that seen without K3. From this it can be inferred that the conversion of T40 → K40 is also reduced to about ½ of that seen without K3.

Example 4 - Toxicity using cell based assay I

Toxicity of the compounds described above was assessed in the T40/12 kD cell assay used to assess activity. Toxicity was measured by cell numbers after 24 hrs exposure to the compound using a lactate dehydrogenase assay kit TOX-7(Sigma Biosciences) according to the manufacturer's instructions after lysis of

remaining cells. Alternatively a kit from Promega UK (CytoTox 96) was used, again according to the manufacturer's instructions.

Two important conclusions emerge from this analysis:

1. There is no correlation between activity of compounds as inhibitors of tau-tau aggregation and their toxicity in the assay;

2. Considering the compounds tested so far, several have similar KI values of about 120 nM corresponding to a B50 cellular activity level of 2.6 µM. However they do differ in relative toxicity, as expressed by the LD50 value. A preferred compound in this group for clinical use may be that which has the highest LD50 value. A therapeutic index (RxIndx) has been calculated for each of compounds tested in the cell assays as follows:

$$RxIndx = LD50 / B50$$

Certain compounds described above can be arranged in order:

Compound	KI (nM)	B50 (µM)	r*	LD50(µM)	Rxindx
K3	128	2.78	0.925	44.92	16.17
DH10	221	4.80	0.935	66.71	13.91
DH5	118	2.56	0.776	34.29	13.39
DH1	513	11.13	0.864	100.97	9.07
DH8	157	3.41	0.964	18.55	5.45
DH13	263	5.71	0.956	30.90	5.41
DH9	127	2.76	0.988	13.09	4.75
DH3	630	13.68	0.944	63.36	4.63

DH11	674	14.63	0.950	12.13	0.83

* is an indication of the goodness of fit of the function to the data.

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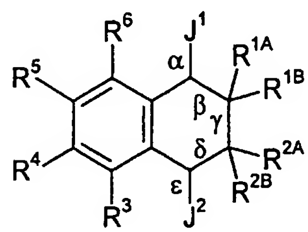
Claims:

1 A compound of formula I for use in the inhibition of the aggregation of a protein, which aggregation is associated with a disease state manifested as neurodegeneration and\or clinical dementia:



I

wherein:

J^1 and J^2 are both =O ; the covalent bonds marked β and δ are single bonds, and the covalent bond marked γ is a double bond with R^{1B} and R^{2B} both absent, or the covalent bond marked γ is a single bond,

or:

J^1 is $-OR^7$ and J^2 is $-OR^8$; the covalent bonds marked β and δ are double bonds, and the covalent bond marked γ is a single bond with R^{1B} and R^{2B} both absent,

wherein:

R^{1A} is selected from -H, unsubstituted C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}hydroxyalkyl, C_{1-7}aminoalkyl, C_{1-7}carboxyalkyl, -OH, C_{1-7}alkoxy, acyloxy, -COOH, ester, $-SO_3H$, $-SO_3M$, sulfonate, C_{1-7}alkylsulfonate, or a short chain alkyl group;

R^{2A} is selected from -H, unsubstituted C_{1-7}alkyl, C_{1-7}haloalkyl, C_{1-7}hydroxyalkyl, C_{1-7}aminoalkyl, C_{1-7}carboxyalkyl, -OH, C_{1-7}alkoxy, acyloxy, -COOH, ester, $-SO_3H$, $-SO_3M$, sulfonate, C_{1-7}alkylsulfonate, or a short chain alkyl group;

R^{1B} if present is selected from the same groups as R^{1A}, and may be the same as or different to R^{1A};

R^{2B} if present is selected from the same groups as R^{2A}, and may be the same as or different to R^{2A};

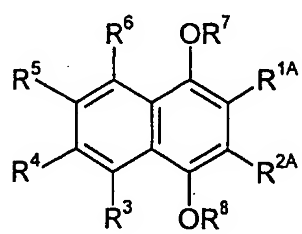
M denotes a cation or cations of charge or cumulative charge to counter the charge on the $-SO_3^-$ group.;

R^3, R^4, R^5, and R^6 is independently -H, -OH, C_{1-7}alkyl, C_{1-7}alkoxy, or acyloxy; and,

R^7 and R^8 is independently -H, C_{1-7}alkyl, acyl, $-SO_3H$, $-SO_3M$, or sulfonate;

and pharmaceutically acceptable salts, solvates, amides, esters, and ethers thereof.

2 A compound as claimed in claim 1 wherein J^1 is $-OR^7$ and J^2 is $-OR^8$; the covalent bonds marked β and δ are double bonds, and the covalent bond marked γ is a single bond with R^{1B} and R^{2B} both absent.



IV

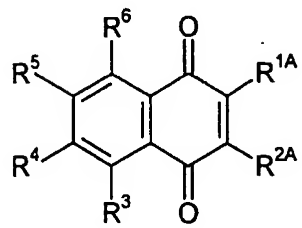
3 A compound as claimed in claim 2 wherein each of R^7 and R^8 is independently -H, -Me, -Et, -C(=O)Me, -C(=O)Et, $-SO_3H$, $-SO_3M$, $-SO_3Me$, or $-SO_3Et$.

4 A compound as claimed in claim 3 wherein each of R^7 and R^8 is independently -H, -Me, -C(=O)Me, $-SO_3H$, $-SO_3M$, or $-SO_3Me$.

5 A compound as claimed in claim 4 wherein each of R^7 and R^8 is -H.

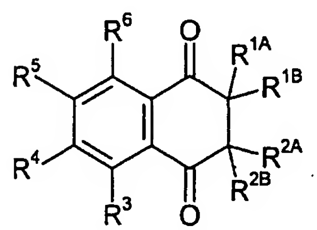
6 A compound as claimed in claim 1 wherein J^1 and J^2 are both

=O; the covalent bonds marked β and δ are single bonds, and the covalent bond marked γ is a double bond with R^{1B} and R^{2B} both absent, and the compound has the formula:



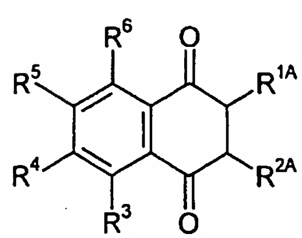
II

7 A compound as claimed in claim 1 wherein J^1 and J^2 are both =O; the covalent bonds marked β and δ are single bonds, and the covalent bond marked γ is a single bond, and the compound has the formula:



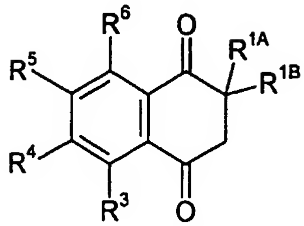
III

8 A compound as claimed in claim 7 wherein R^{1B} and R^{2B} are both -H:



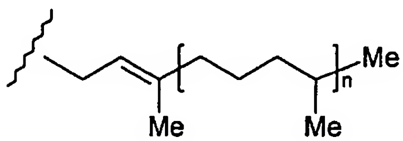
VIII

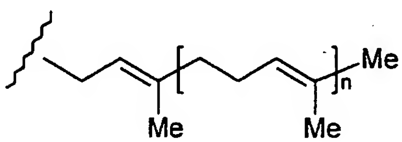
9 A compound as claimed in claim 7 wherein R^{2A} and R^{2B} are both -H:



VII

10 A compound as claimed in any one of claims 1 to 8 wherein the short chain alkyl group in R^{2A} is one of the following groups, wherein n is 0, 1, or 2:





11 A compound as claimed in any one of claims 1 to 8 wherein each of R^{1A}, R^{2A}, and R^{1B} and R^{2B} if present, is independently -H; -Me, -Et, -nPr, -iPr, -nBu, -sBu, -iBu, -tBu; -OH; -OMe, -OEt, -O(nPr), -O(iPr), -O(nBu), -O(sBu), -O(iBu), -O(tBu); -OC(=O)Me, -OC(=O)Et, -OC(=O)(nPr), -OC(=O)(iPr), -OC(=O)(nBu), -OC(=O)(sBu), -OC(=O)(iBu), -O(C=O)(tBu); -C(=O)OMe, -C(=O)OEt, -C(=O)O(nPr), -C(=O)O(iPr), -C(=O)O(nBu), -C(=O)O(sBu), -C(=O)O(iBu), -C(=O)O(tBu); $-SO_3H$, $-SO_3M$, $-SO_3Me$, $-SO_3Et$, $-SO_3(nPr)$, $-SO_3(iPr)$, $-SO_3(nBu)$, $-SO_3(sBu)$, $-SO_3(iBu)$, or $-SO_3(tBu)$.

12 A compound as claimed in claim 11 wherein each of R^{1A}, R^{2A}, and R^{1B} and R^{2B} if present, is independently -H, -Me, -Et, -OMe, -OEt, -OH, -OMe, -OEt, -OC(=O)Me, -OC(=O)Et, -COOH, -COOMe, -COOEt, $-SO_3H$, $-SO_3M$, $-SO_3Me$, $-SO_3Et$, or $-CH_2CH=C(CH_3)_2$.

13 A compound as claimed in claim 12 wherein each of R^{1A}, R^{2A}, and R^{1B} and R^{2B} if present, is independently -H, -Me, -OMe, -OH, -OMe, -OC(=O)Me, -COOH, -COOMe, $-SO_3H$, $-SO_3M$, $-SO_3Me$, or $-CH_2CH=C(CH_3)_2$.

14 A compound as claimed in any one of the preceding claims wherein each of R^3, R^4, R^5, and R^6 is independently: -H, -OH, -Me, -Et, -OMe, -OEt, -OC(=O)Me, or -OC(=O)Et.

15 A compound as claimed in claim 14 wherein each of R^3, R^4, R^5, and R^6 is independently: -H, -OH, -Me, -OMe, or -OC(=O)Me.

16 A compound as claimed in claim 15 wherein each of R^3, R^4, R^5, and R^6 is independently: -H or -OH.

17 A compound as claimed in claim 16 wherein each of R^4, R^5, and R^6 is -H.

18 A compound as claimed in any one of the preceding claims wherein R^3 is -H.

19 A compound as claimed in any one of claims 1 to 17 wherein R^3 is -OH.

20 A compound as claimed in claim 6 wherein R^{1A} is methyl, and each of R^{2A}, R^3, R^4, R^5, and R^6 is -H.

21 A compound as claimed in claim 6 wherein R^{1A} is $-SO_3H$ or $-SO_3M$, and each of R^{2A}, R^3, R^4, R^5, and R^6 is -H.

22 A compound as claimed in claim 6 wherein R^{1A} and R^{2A} are methyl, and each of R^3, R^4, R^5, and R^6 is -H.

23 A compound as claimed in claim 6 wherein R^{1A} is methyl and R^3 is -OH, and each of R^{2A}, R^4, R^5, and R^6 is -H.

24 A compound as claimed in claim 6 wherein R^{1A} is -OMe, and each of R^{2A}, R^3, R^4, R^5, and R^6 is -H.

25 A compound as claimed in claim 6 wherein R^{1A} is methyl and R^{2A} -OMe, and each of R^3, R^4, R^5, and R^6 is -H.

26 A compound as claimed in claim 6 wherein R^{1A} is -COOH; each of R^{2A}, R^3, R^4, R^5, R^6 is -H; and R^7 and R^8 are -OH.

27 A compound as claimed in claim 6 wherein R^{1A} is methyl; each of R^{2A}, R^3, R^4, R^5, R^6 is -H; and R^7 and R^8 are -C(=O)Me.

28 A compound as claimed in claim 6 wherein R^{1A} is methyl; each of R^{2A}, R^3, R^4, R^5, R^6 is -H; and R^7 and R^8 are both either $-SO_3H$ or $-SO_3M$.

29 A compound as claimed in claim 6 wherein R^{1A} and R^{2A} are methyl; each of R^3, R^4, R^5, R^6 is -H; and R^7 and R^8 are -C(=O)Me.

30 A compound as claimed in any one of the preceding claims wherein M, if present, is selected from the group consisting of: Na^+ and K^+.

31 A compound as claimed in any one of the preceding claims which has an B50 value obtained as determined with reference to the Examples herein of < 20.

32 A compound as claimed in any one of the preceding claims which has an Rxindx value obtained as determined with reference to Example 4 herein of greater than 4.

33 Use of a compound as claimed in any one of the preceding claims to inhibit the aggregation of a protein, which aggregation is associated with a disease state manifested as neurodegeneration and\or clinical dementia.

34 Use of a compound as claimed in any one of claims 1 to 32 in the preparation of a medicament to inhibit the aggregation of a protein, which aggregation is associated with a disease state manifested as neurodegeneration and\or clinical dementia.

35 Use of a compound as claimed in any one of claims 1 to 32 in a method of treatment or prophylaxis of a neurodegenerative disease and\or clinical dementia associated with protein aggregation, which method comprises administering to a subject a prophylactically or therapeutically effective amount of a compound as claimed in any one of claims 1 to 32, or a therapeutic composition comprising the

same, such as to inhibit the aggregation of the protein associated with said disease or dementia.

36 A method of treatment or prophylaxis of a neurodegenerative disease and\or clinical dementia associated with protein aggregation, which method comprises administering to a subject a prophylactically or therapeutically effective amount of a compound as claimed in any one of claims 1 to 32, or therapeutic composition comprising the same, such as to inhibit the aggregation of the protein associated with said disease or dementia.

37 A use or method as claimed 35 or claim 36 wherein the compound is used in combination with another treatment for said disease or dementia.

38 A compound, use, or method as claimed in any one of the preceding claims wherein the protein is tau protein.

39 A compound, use, or method as claimed in any one of the preceding claims wherein the disease is selected from the list consisting of Familial Multiple System Tauopathy, Corticobasal Degeneration, Familial Gerstmann-Straussler-Scheinker Disease, Motor Neurone Disease; Lewy body disease; Pick's disease; Progressive Supranuclear Palsy; Alzheimer's disease.

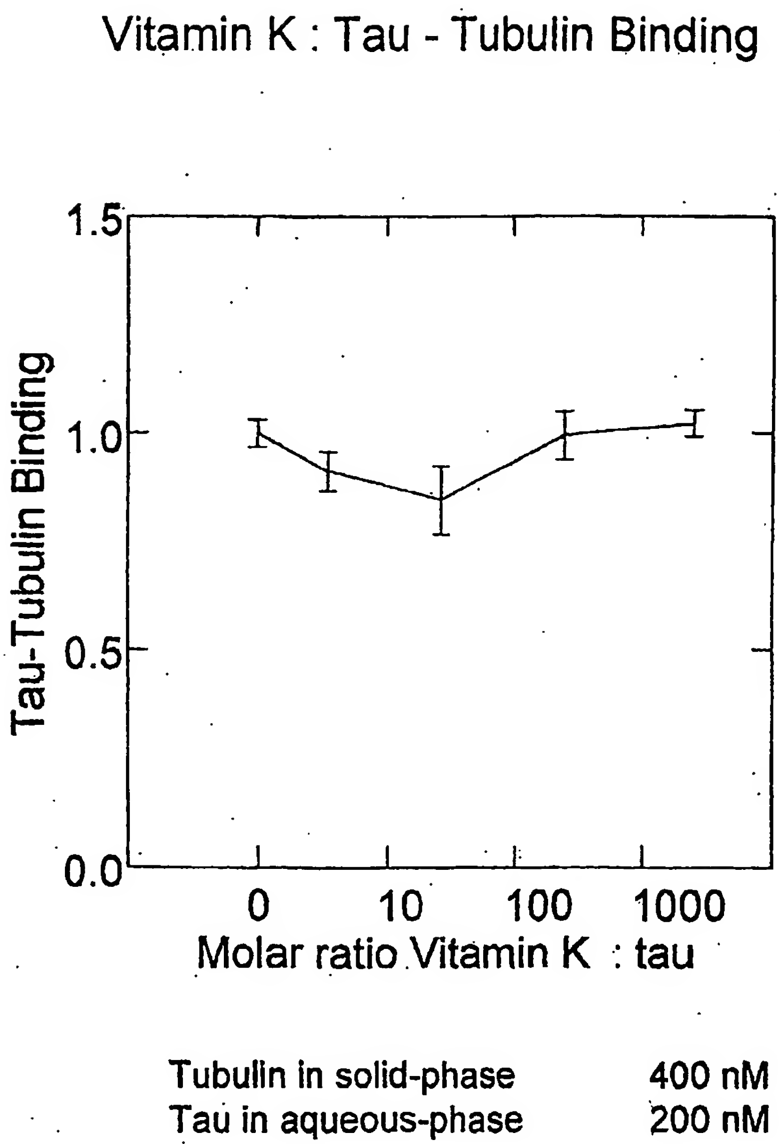

Vitamin K : Tau - Tubulin Binding
1.5
1.0
0.5
0.0
Tau-Tubulin Binding
0
10
100
1000
Molar ratio Vitamin K : tau
Tubulin in solid-phase 400 nM
Tau in aqueous-phase 200 nM

Figure 1

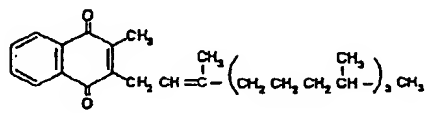
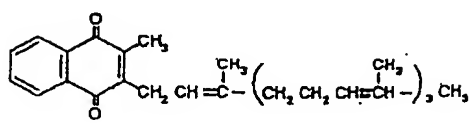
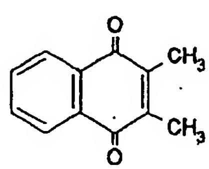
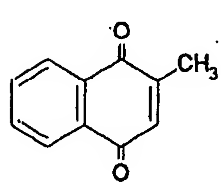
		KI (nM)	B_{50} (μM)
II			
	K_1	1605	59.83
	K_2	1540	33.46
	DH10	221	4.80
	K_3	128	2.78

Figure 2a

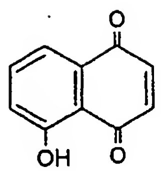
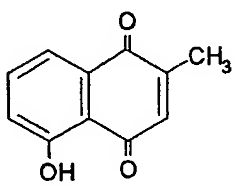
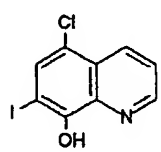
		KI (nM)	B 50 (μM)
III			
	DH14	—	—
	DH2	131	2.85
	DH16	—	—

Figure 2b

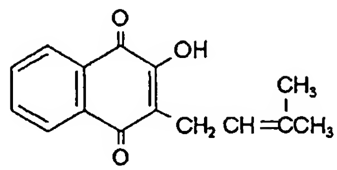
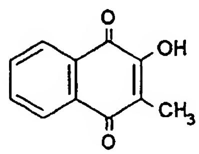
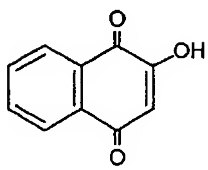
		KI (nM)	B 50 (μM)
IV			
	DH1	513	11.14
	DH15	—	—
	DH7	—	—

Figure 2c

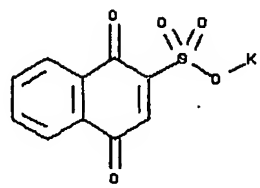
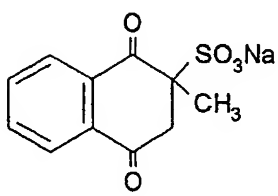
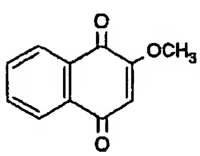
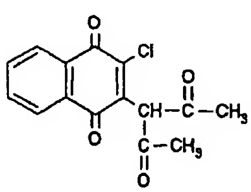
		KI (nM)	B_{50} (μM)
V			
	DH8	157	3.41
	DH3	630	13.68
	DH17	293	6.4
	DH19	—	—

Figure 2d

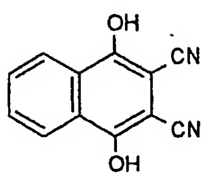
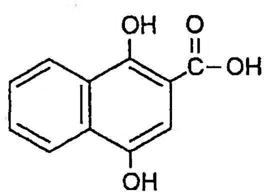
		KI (nM)	B $_{50}$ (μM)
VI			
	DH4	—	—
	DH5	118	2.56

Figure 2e

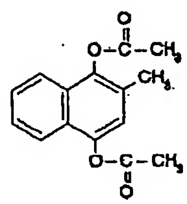
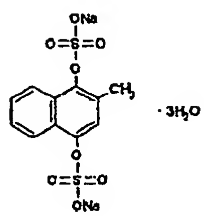
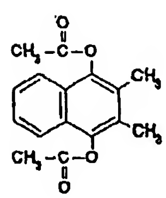
		KI (nM)	B_{50} (μM)
VII			
	DH9	127	2.76
	DH13	263	5.71
	DH11	674	14.62

Figure 2f

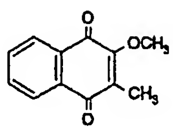
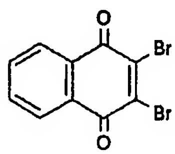
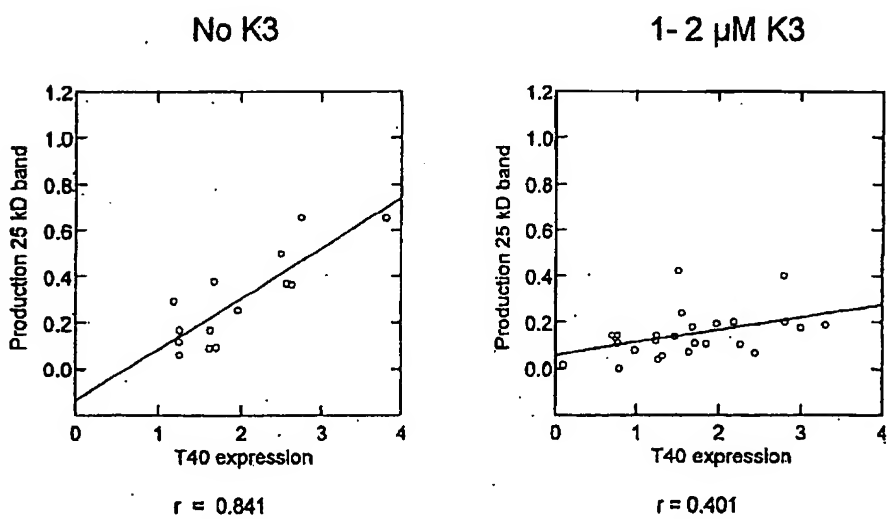
		KI (nM)	B 50 (μM)
VIII			
	DH18		35
	DH20	—	—

Figure 2g

Inhibition of production of 25 kD band (K25) from full-length tau (T40) in the presence of Vitamin K3



Production of 25 kD band:

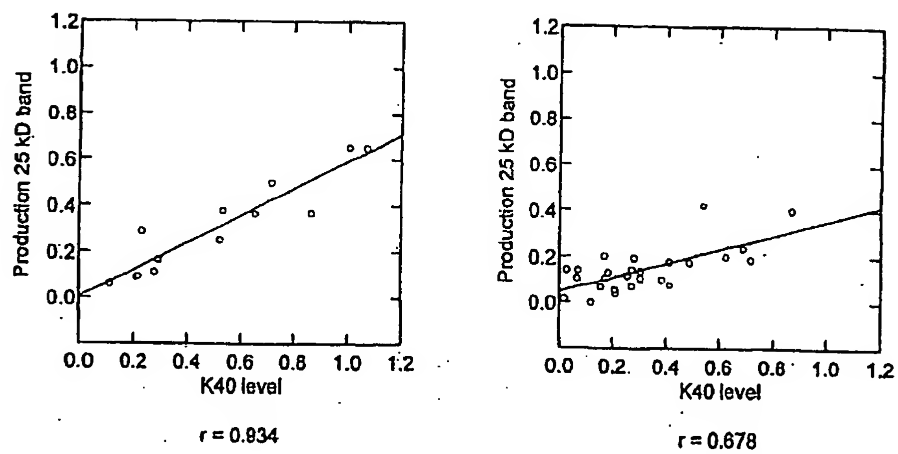
No K3	*22% of T40*
1-2 µM K3	*5% of T40*

$p = 0.0015$

Figure 3a

Inhibition of production of 25 kD band (K25) from K40 tau fragment (SS190-441) in the presence of Vitamin K3

No K3 1- 2 μM K3



Production of 25 kD band:

No K3	*59% of K40*
1-2 μM K3	*31% of K40*

$p = 0.0012$

Figure 3b

Diseases of protein aggregation

Protein	Disease	Aggregating domain and/or mutations	Fibril subunit size (kDa)	Reference
Neurodegenerative disorders				
Prion protein	Prion diseases (CJD, nvCJD, Fatal familial insomnia, Gerstmann-Straussler-Scheinker syndrome, Kuru)	*Inherited and sporadic forms* PrP-27-30; many mutations Fibrillogenic domains: 113-120, 178-191, 202-218	27	Prusiner (1998) Gasset et al. (1992)
Tau protein	Alzheimer's disease, Down's syndrome, FTDP-17, CBD, post-encephalitic parkinsonism, Pick's disease, parkinsonism with dementia complex of Guam	*Inherited and sporadic forms* Truncated tau (tubulin-binding domain) 297-391 Mutations in tau in FTDP-17 Many mutations in presenilin proteins	10-12	Wischik et al. (1988) Hutton et al. (1998) Czech et al. (2000)
Amyloid β-protein	Alzheimer's disease, Down's syndrome	*Inherited and sporadic forms* Amyloid β-protein; 1-42(3); 11 mutations in APP in rare families	4	Glenner & Wong, (1984) Goate et al. (1991)
Huntingtin Ataxins (1, 2, 3, 7) Atrophin Androgen receptor	Huntington's disease Spinocerebellar ataxias (SCA1, 2, 3, 7) Dentarubropallidoluysian atrophy (DRPLA) Spinal and bulbar muscular atrophy	N-termini of protein with expanded glutamine repeats Proteins with expanded glutamine repeats Proteins with expanded glutamine repeats Proteins with expanded glutamine repeats	40	DiFiglia et al. (1997) Paulson et al. (1999) Paulson et al. (1999) Paulson et al. (1999)
Neuroserpin	Familial encephalopathy with neuronal inclusion bodies (FENIB)	Neuroserpin; S49P, S52R	57	Davis et al. (1999)
α-Synuclein	Parkinson's disease, dementia with Lewy bodies, multiple system atrophy	*Inherited and sporadic forms* A53T, A30P in rare autosomal-dominant PD families	19	Spillantini et al. (1998) Polymeropoulos et al. (1997)
Cystatin C	Hereditary cerebral angiopathy (Icelandic)	Cystatin C less 10 residues; L68Q	12-13	Abrahamson et al. (1992)
Superoxide dismutase 1	Amyotrophic lateral sclerosis	SOD1 mutations		Shibata et al. (1996)
Non-neurodegenerative disorders				
Haemoglobin	Sickle cell anaemia Inclusion body haemolysis	Haemoglobin beta chain (S) Many mutations		Carrell & Gooptu (1998)
Serpins	α1-Antitrypsin deficiency (emphysema, cirrhosis) Antithrombin deficiency (thromboembolic disease) C1-inhibitor deficiency (angioedema)	Mutations Mutations Mutations		Lomas et al. (1992) Carrell & Gooptu (1998) Carrell & Gooptu (1998)
Immunoglobulin light chain	Plasma cell dyscrasias (primary systemic AL amyloidosis)	light chain or fragments	0.5-25	Westermark et al. (1985)
Serum amyloid A	Reactive, secondary systemic AA amyloidosis Chronic inflammatory disease	76-residue fragment (critical residues 2-12)	4.5-7.5	Westermark et al. (1985)

Figure 4

Transthyretin	Familial amyloid polyneuropathy (systemic; FAP I)	Tetramer dissociated to conformational monomer variant Many mutations (some not associated with amyloid; several different types of disease)	10-14	Gustavsson et al. (1991)
	Senile cardiac amyloidosis	Normal transthyretin	10-14	Gustavsson et al. (1991)
Gelsolin	Familial amyloidosis - Finnish type (FAP IV)	D187Q leads to truncated 173-225/243 (critical residues 182-192)	9.5	Maury & Baumann (1990)
β2-Microglobulin	Haemodialysis amyloidosis Prostatic amyloid	β2-Microglobulin	12-25	Gorevic et al. (1985)
Apolipoprotein AI	Familial amyloid polyneuropathy (systemic; FAP III)	N-terminal 83-93 residues; G26R, W50R, L60R	9	Booth et al. (1997)
Lysozyme	Familial visceral amyloidosis	Lysozyme or fragments (with or without I56T, D67H)	14	Pepys et al. (1993)
Amylin (islet amyloid polypeptide)	Type II diabetes (NIDDM)	Fragments (critical core of 20-29); no mutations	3.9	Westermark (1990)
Fibrinogen α-chain	Hereditary renal amyloidosis	Fibrinogen fragments	7-10	Uemichi et al. (1992)
Procalcitonin	Medullary carcinoma of thyroid	Calcitonin fragments	3.4	Sletten et al. (1976)
Atrial natriuretic factor	Cardiac amyloidosis	ANF, no mutants	3.5	Johansson et al. (1987)
Insulin	Injection localised amyloidosis	Insulin		Dische et al. (1988)
Other proteins forming amyloid	*(In vitro)*	Other proteins		Chiti et al. (1999)

Figure 4 Cont ...

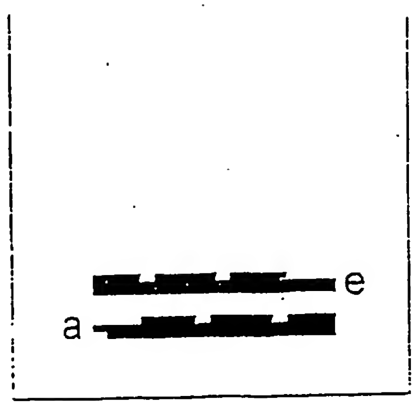


Figure 5

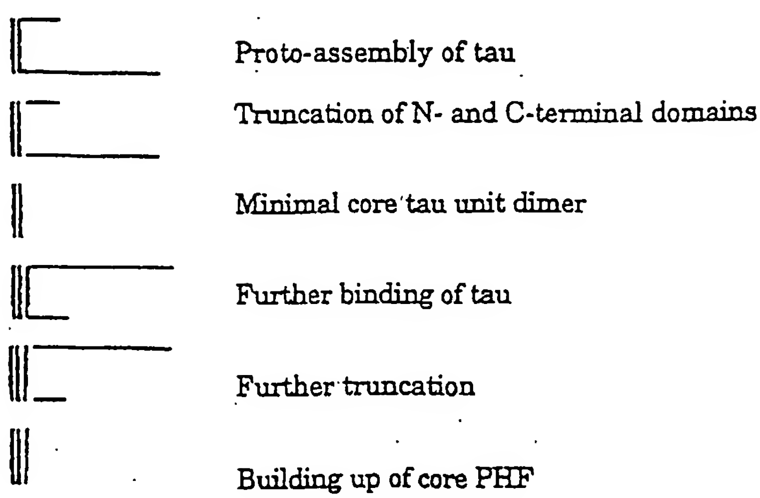


Figure 6a

DH15 : 12 kD model

↑T40 + 12 kD ⇒ ↑12 kD cell assay

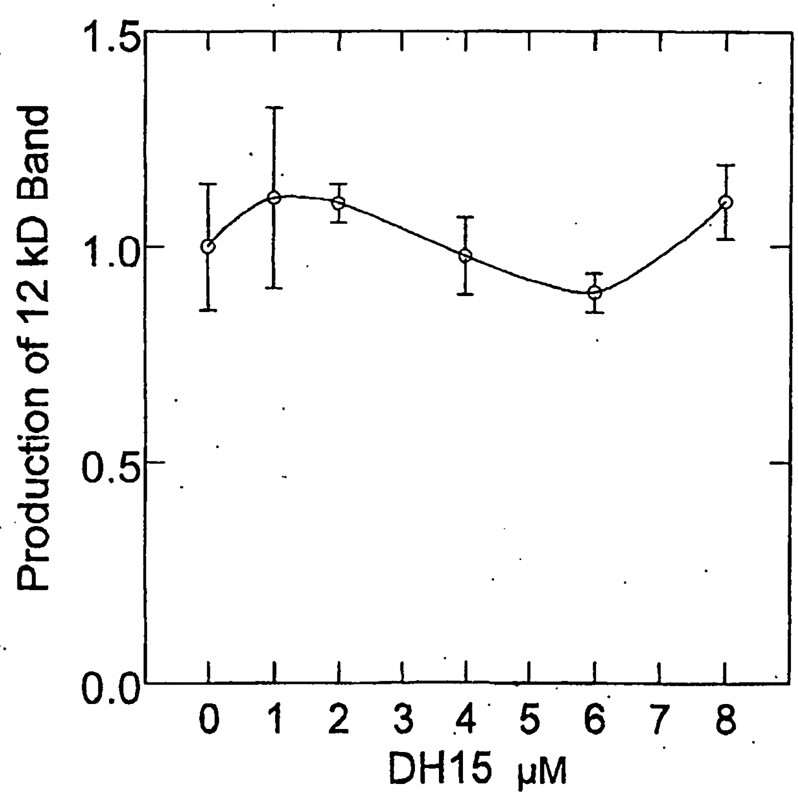


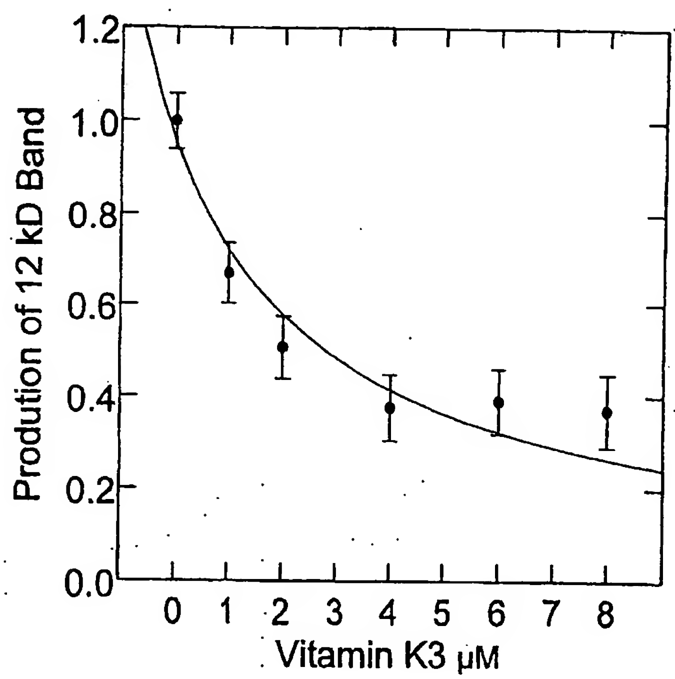
Figure 6b

Vitamin K3 : 12 kD model

↑T40 + 12 kD ⇒ ↑12 kD cell assay

Cellular activity predicted via standard inhibition model:

acitivity = [tau] / ([tau] + Kd * (1 + [VK3] / KI))



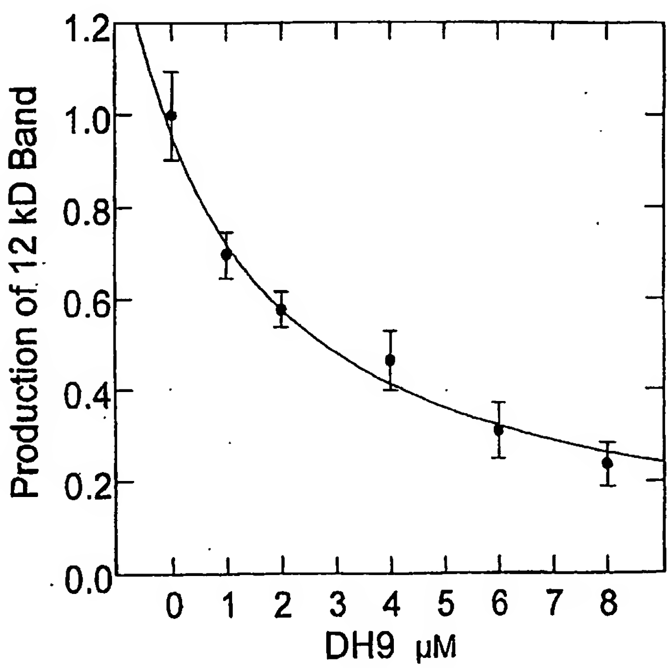
Observed vs predicted activity	r = 0.925
Intracellular tau concentration	500 nM
Tau-tau binding affinity	22 nM
Vitamin K3 KI	128 nM

Figure 6c

DH9 : 12 kD model
↑T40 + 12 kD ⇒ ↑12 kD cell assay

Cellular activity predicted via standard inhibition model:

acitivity = [tau] / ([tau] + Kd * (1 + [DH9] / KI))



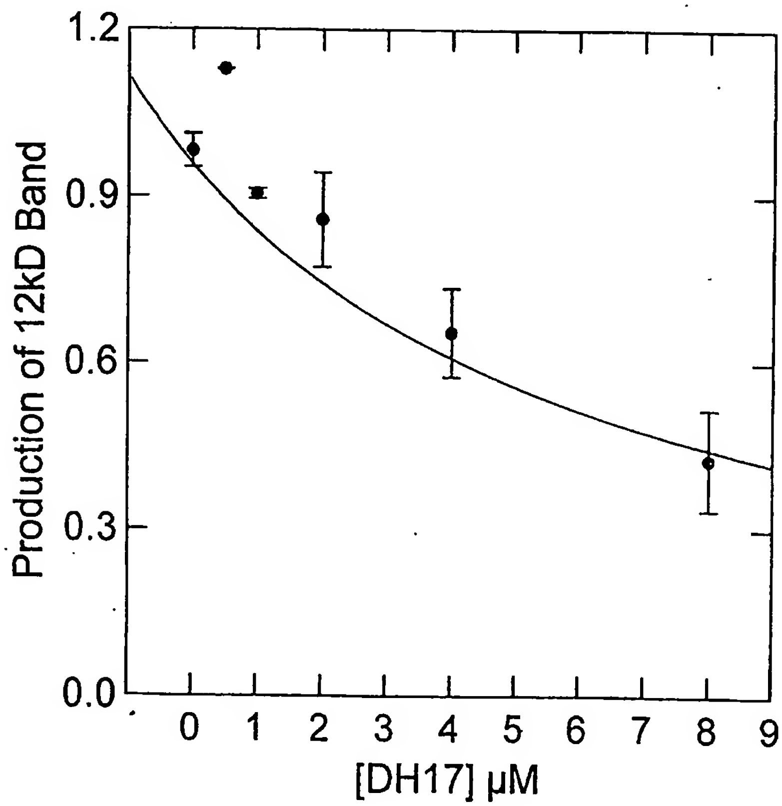
Observed vs predicted activity	r = 0.988
Intracellular tau concentration	500 nM
Tau-tau binding affinity	22 nM
DH9 KI	127 nM

Figure 6d

DH17 : 12kD model
↑T40 + 12 kD ⇒ ↑ 12kD

Cellular activity predicted via standard inhibition model:

activity = [tau]/([tau]+Kd*(1+[DH17]/Ki))



Observed vs predicted activity	r=0.808
Intacellular tau concentration	500nM
Tau-tau binding affinity	22nM
DH17 Ki	293nM

Figure 6e

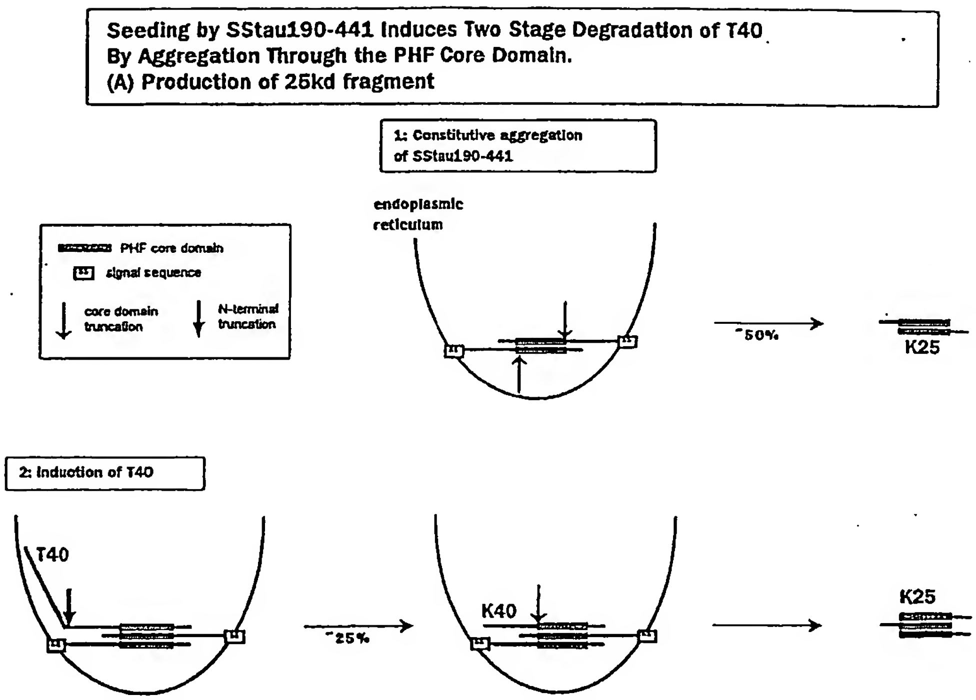

Seeding by SStau190-441 Induces Two Stage Degradation of T40
By Aggregation Through the PHF Core Domain.
(A) Production of 25kd fragment
1: Constitutive aggregation of SStau190-441
endoplasmic reticulum
PHF core domain
signal sequence
core domain truncation
N-terminal truncation
~50%
K25
2: Induction of T40
T40
~25%
K40
K25

Figure 7a

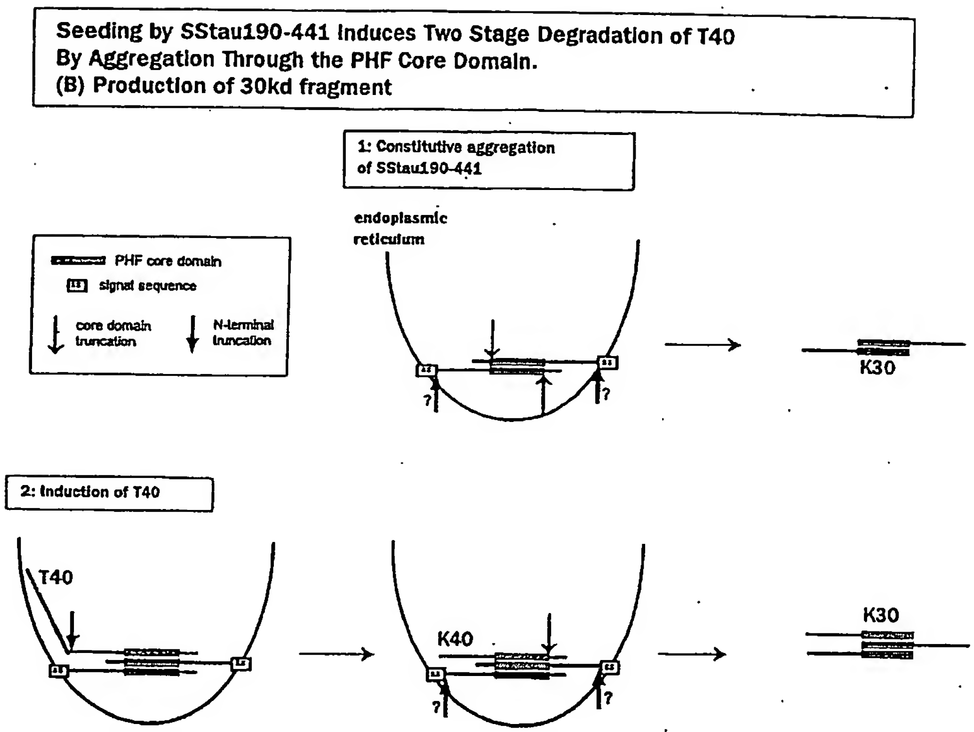

Seeding by SStau190-441 Induces Two Stage Degradation of T40
By Aggregation Through the PHF Core Domain.
(B) Production of 30kd fragment
1: Constitutive aggregation of SStau190-441
endoplasmic reticulum
PHF core domain
signal sequence
core domain truncation
N-terminal truncation
K30
2: Induction of T40
T40
K40
K30

Figure 7b